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A COMPARISON OF PIONEER VENUS AND VENERA BOW SHOCK OBSERVATIONS: EVIDENCE FOR A SOLAR CYCLE VARIATION

J.A. Slavin, R.C. Elphic and C.T. Russell

Institute of Geophysics and Planetary Physics,
University of California, Los Angeles, California 90024

Abstract. Observations by the Venera 9 and 10 orbiters in 1975-76 have been used in previous studies to determine the mean location and shape of the Cytherean bow shock. In addition it has also been reported that the shock is found to be more distant from the planet above regions of the ionosheath where draped IMF field lines are oriented perpendicular to the flow as opposed to parallel. An examination of the dependence of shock altitude in the terminator plane on upstream IMF direction using 86 Pioneer Venus orbiter bow shock crossings in 1978-79 sets an upper limit on this asymmetry of 12% or approximately half that derived earlier from the Venera data. More significantly, the mean distance to the bow shock observed by Pioneer Venus Orbiter is 35% greater than was the case in 1975-76 near solar minimum. As the growth in effective obstacle radius is an order of magnitude larger than can be accounted for in terms of varying ionopause altitude due to all causes, these results strongly suggest that Venus can absorb significantly more of the incident solar wind plasma during solar minimum when EUV flux is low than during the current epoch in which maximum is approaching.

Introduction

Observations made by the Pioneer Venus orbiter (PVO) have confirmed the inference based on earlier missions (see reviews by Breus, 1979; Russell, 1979) that the solar wind flow incident on Venus is deflected about the planet by an ionopause with the formation of a bow shock (Wolfe et al., 1979; Russell et al., 1979a; Brace et al., 1979; Elphic et al., 1979). Interplanetary conditions have been shown to play a significant role in determining the structure of the upper ionosphere by supplying an external heat source (Knudsen et al., 1979), by imposing magnetic fields of solar wind origin throughout the ionosphere (Russell et al., 1979a,b,c; Russell and Elphic, 1979), and providing the external pressure which confines the ionosphere and at least in part sets ionopause altitude (Russell et al., 1979c). The influence of solar EUV radiation intensity on ionopause height has not yet been firmly established, but may be of importance particularly in the study of solar cycle variations in the solar wind interaction with Venus (Wolff et al., 1979; and references therein).

The low altitude of the effective obstacle to the solar wind at Venus which PVO shock positions suggest to be near the surface of the planet (Slavin et al., 1979) results in the magnetosheath flow being located in a region of space which is permeated by a large population of exospheric neutrals as compared with the situation at Jupiter or the earth. Models based on the findings of previous missions predict number densities of $\sim 10^2$ to $\sim 5\times10^4 cm^{-3}$ for O, He, H_2, and H at altitudes near 500 km (e.g. Cloutier and Daniell, 1979). In addition, exospheric hydrogen at altitudes of several thousand kilometers has been found to be variable with Mariner 10 UV observations near solar minimum in 1974 indicating only half the densities inferred from Mariner 5 measurements as solar maximum neared in 1967 (Broadfoot et al., 1974). Both charge exchange (Wallis, 1973; 1974) and photoion pickup (Cloutier et al., 1974) have been proposed as a means of coupling the neutrals to the flowing plasma in the magnetosheath. It has been suggested on theoretical grounds that such interactions between these particle populations will result in an enhanced escape flux from the exosphere (Michel, 1971; Cloutier et al., 1974; Kumar et al., 1978), a weak bow shock (Wallis, 1973), and an asymmetry in shock altitude with respect to the orientation of the interplanetary magnetic field (IMF) component perpendicular to the solar wind velocity vector (Cloutier, 1976). The existence of the first two of these phenomena is supported by both the Venera and Mariner missions' observations indicating the presence of a hot non-thermal hydrogen corona at Venus (Barth et al., 1968; Kumar et al., 1978) and the PVO discovery that the Cytherean bow shock is in fact weaker than its terrestrial analogue (Russell et al., 1979b). A study by Romanov et al. (1977) using 17 bow shock crossings by the orbiters Venera 9 (V9) and Venera 10 (V10) has reported that this boundary is located more distant from the planet in directions perpendicular to the transverse component of the IMF. Cloutier (1976) proposed an effect of this type to be associated with both MHD flow characteristics about any blunt obstacle and due to the preferential accretion of exospheric photoions by the magnetosheath flow over regions of the ionosphere where the $-\underline{V}\times\underline{B}$ electric field is directed outward from the planet along with a minimum pickup efficiency where the magnetic field and flow vectors are more nearly parallel. In addition to these "cometary" processes possibly playing roles in the solar wind interaction with Venus the degree to which this planet absorbs portions of the incoming solar wind has not yet been well determined although the highly variable position of the shock reported by Slavin et al. (1979) suggests that Venus cannot always be a perfect deflector.

In this paper a comparison is made between the location of the bow shock observed by V9 and V10 in late 1975 and early 1976 and its dependence on IMF orientation with the PVO observations from December 1978 through February 1979. As the Venera and Pioneer Venus missions examine the shock at different times of the solar cycle and in

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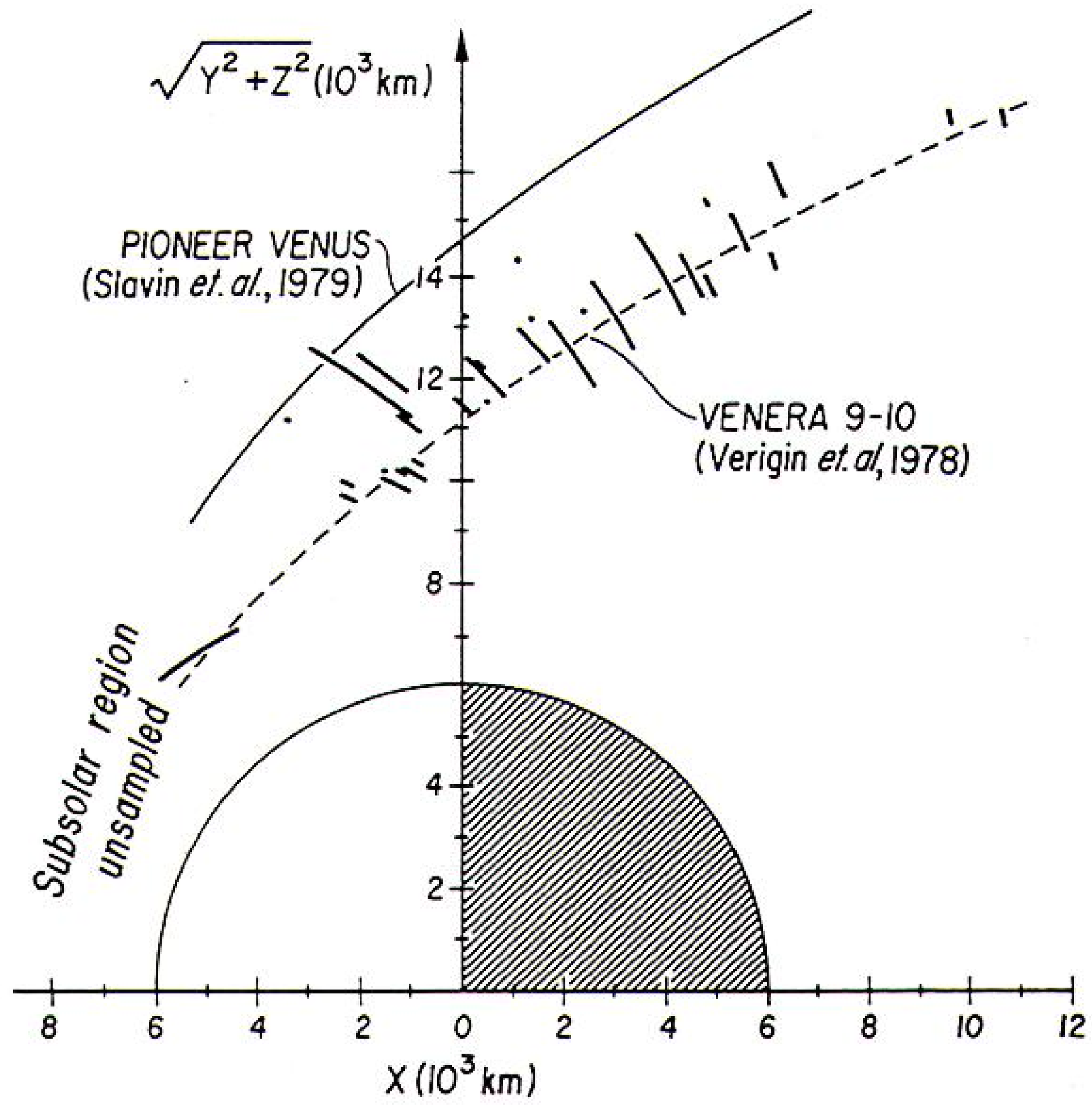

Figure 1. The position of the Venus bow shock on 33 occasions is plotted in VSE coordinates as solid line segments whose length reflect experimental uncertainty (Verigin et al., 1978). A theoretical shock curve fit to the data by Verigin et al. is marked by a dashed line. The solid curve is the best fit conic to 86 Pioneer Venus shock crossings by Slavin et al. (1979).

different spatial regions with respect to the average IMF orientation, the comparison can provide information on both of these aspects of the solar wind interaction with Venus.

Venera 9 and 10 and Pioneer Venus Shock Observations

Figure 1 displays as solid line segments bow shock encounters detected from the wide-angle plasma analyzer data from V9 and V10 on 33 passes in 1975-76 by Verigin et al. (1978). The orbits of the two satellites were very similar with their 30° inclination generally producing shock crossings near the plane of the ecliptic (Verigin et al., 1978). A dashed line shows the best fit by Verigin et al. of the theoretical shock surface of Spreiter et al. (1970) to the observations. A mean altitude in the terminator plane of 5000km is found along with a small variance from the mean producing only 6 encounters deviating by more than 1000km from their fitted curve.

The solid curved line in Figure 1 represents the best fit conic to the 86 bow shock crossings by Pioneer Venus from early December, 1978 through early February, 1979 identified by Slavin et al. (1979). It should be noted that the PVO and Venera crossings used in determining the mean shock surfaces displayed occurred over similar ranges in SVS angle so that there is no fitting bias present. As shown, this curve intersects the terminator nearly 4000km farther from the planet than does the Venera plot. While not shown, the spread in position about the mean was much larger for the PVO observations with one standard deviation in the plane of the terminator being 1400km, or about twice the width of the Venera distribution.

As the different instruments and methods used by Verigin et al. (1978) and Slavin et al. (1979) to identify shock crossings could not account for any but a small portion of the discrepancy between the two curves in Figure 1, the lack of agreement must be explained in terms of physical phenomena. The two most likely possibilities are an increase in shock height at Venus between 1975-76 and 1978-79 presumably associated with the solar cycle variations in the sun's particle and electromagnetic emissions and/or an asymmetry in shock altitude between the ecliptic plane, probed by V9 and V10, and the regions "above" and "below" that plane examined by PVO with its 105° inclination orbit. The latter difference in boundary position would presumably be associated with the asymmetry hypothesis of Cloutier (1976) and Romanov et al. (1977) and the strong tendency of the IMF to lie parallel to the plane of the ecliptic.

The possibility of an asymmetry in the shock surface with respect to the orientation of the IMF in the plane perpendicular to the upstream solar wind velocity vector can be examined directly by plotting distance to the shock in the terminator plane as a function of observed IMF direction for each crossing as is done in Figure 2. For all 86 PVO bow shock crossings presented by Slavin et al. (1979) a shock location in the solar wind aberrated terminator plane is inferred using the mean surface displayed as a solid line in Figure 1 to map crossings into that plane. The angle measured counterclockwise as viewed from the sun between the upstream IMF vector projected into the terminator plane and the shock position vector in that plane is termed Δ_{XB}. The photoion pickup model of Cloutier (1976; see also Cloutier et al., 1974) would predict a maximum shock altitude at Δ_{XB}=90° and minima at Δ_{XB}=0°, 180°. Romanov et al. (1977) looked for such an asymmetry using 17 Cytherean shock positions determined with data from the RIEP spectometer on V9 and V10 ranging between x_{VSE}=+1 to -8R. Their crossings have only a few in common with the Venera passes

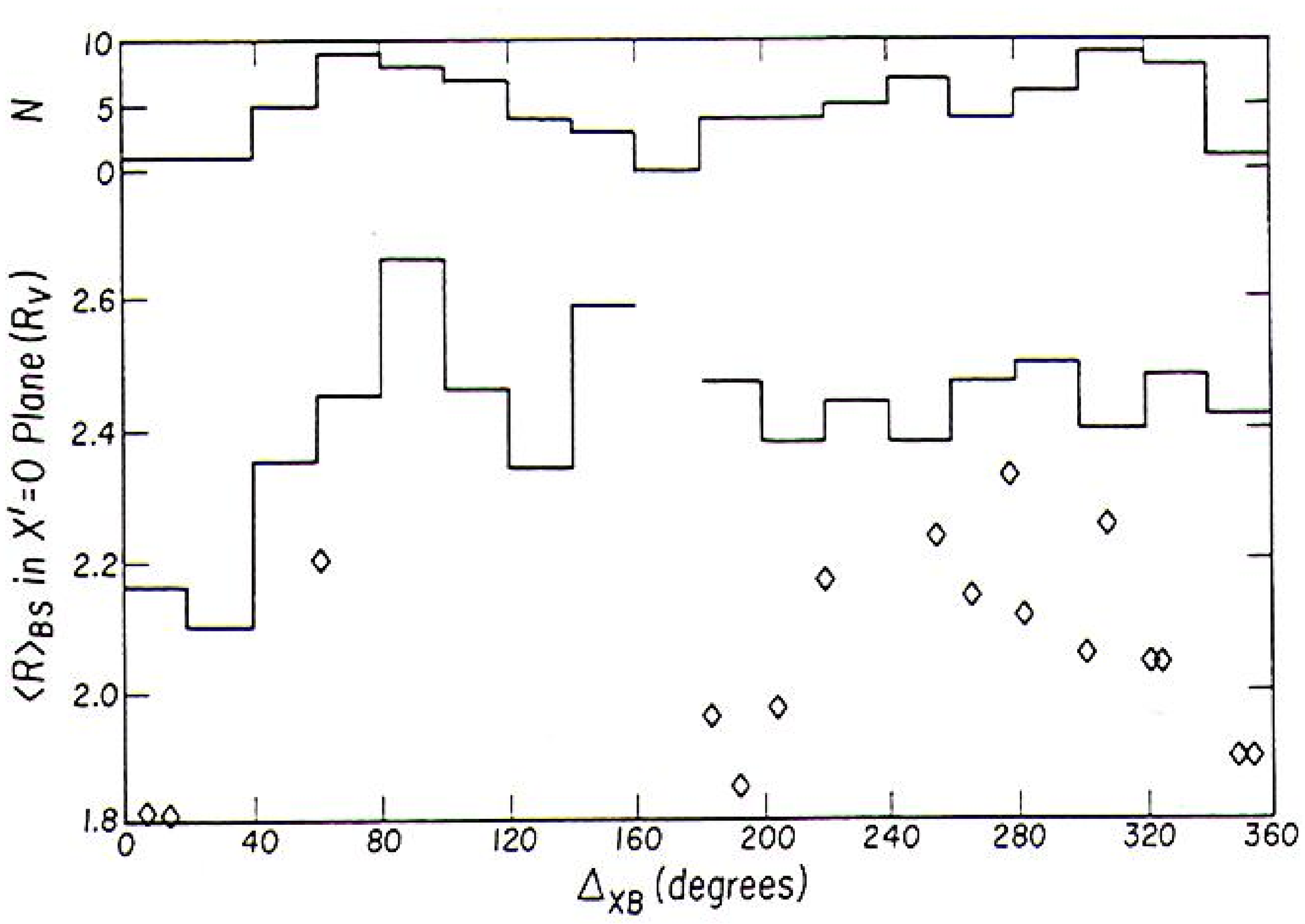

Figure 2. Solid lines show the average shock distance in the solar wind aberrated terminator plane per 10° bin for the 86 shock crossings by PVO considered by Slavin et al. (1979) plotted versus Δ_{XB}. A histogram at the top of the figure displays the number of crossings in each bin. Diamond shapes mark the positions of the 17 Venera 9 and 10 shock encounters from the study by Romanov et al. (1977).

examined by Verigin et al. (1978) to obtain the mean shape shown in Figure 1. The 17 shock crossings were mapped from farther downstream into the terminator plane by Romanov et al. using the theoretical surfaces from Spreiter et al. (1970). The altitude of each shock crossing in the terminator plane from Romanov et al. has been plotted versus Δ_{XB} in Figure 2 with diamond shapes. It was concluded by Romanov et al. the Venus bow shock was indeed asymmetric with respect to IMF orientation by $0.36 \pm .13$ R_V on the basis of the peak in altitude at Δ_{XB}=270-290°. A solid line indicates the average shock distance per 10° bin found by PVO. The number of crossings averaged in each bin, ranging from 0 to 9, is displayed at the top of the plot as a histogram. The PVO observations in Figure 2 suggest the possibility of a peak at Δ_{XB}=90°, but little else. While there is no sign of the maximum at Δ_{XB}=270-290° reported by Romanov et al. (1977) on the basis of much fewer crossings, a global asymmetry in altitude at the terminator of ≤ 0.2 R_V might not be apparent given the scatter in shock location due to other causes and the paucity of data for some IMF directions. Larger asymmetries are precluded by the data in Figure 2.

Solar Cycle Variations

As discussed in the preceeding section, it does not appear that more than a third of the 0.6 R_V difference in terminator altitude displayed in Figure 1 can be explained in terms of a spatial asymmetry with respect to IMF direction biasing the comparison between V9, V10 and PVO. Most of the difference must then be due to a real increase in shock altitude between the 1975-76 and 1978-79 observations. Both the EUV flux from the sun which is expected to influence the upper ionosphere/exosphere and solar wind conditions are known to vary with solar cycle (Hinteregger, 1979; Hundhausen, 1975; Gosling et al., 1976; Feldman et al., 1978). However, while shock position associated with a "hard" obstacle is a function of interplanetary conditions (see Slavin et al., 1979; and references therein), no significant variation in the ratio of shock distance to obstacle distance with solar cycle has been reported at the earth (e.g. Egidi et al., 1970; Fairfield, 1971). Hence, an increase in shock altitude requires a similar growth in the effective obstacle size at Venus. A recent model of ionopause altitude by Wolff et al. (1979) makes use of the factor of 2 increase in EUV flux between 1975-76 and 1978-79 to reconcile the larger ionopause heights found by PVO relative to those inferred from the Venera measurements (see Breus, 1979). However, changing ionopause altitude can alter total obstacle radius by only a few percent as discussed by Slavin et al. (1979). Accordingly, the variation in shock location as solar maximum approaches is most likely related to the ability of the Cytherean exosphere/ionosphere to act as a source and/or sink for magnetosheath particles being affected by the variation in EUV as well as solar wind conditions. Using the upper estimate of 0.2 R_V on the radial asymmetry of the shock in the terminator plane a lower limit of 23% on the increase in effective obstacle size at Venus during the last three years is determined. PVO observations of the solar wind interaction with Venus during solar maximum and beyond should provide important additional information on the nature of solar cycle influence on this planet.

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